LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-TR-214269

Test Plan for Godiva Move from LANL TA-18 to Nevada Test Site Device Assembly Facility

M. Garcia

August 8, 2005

Auspices Statement

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Test Plan for Godiva Move from LANL TA-18 to NTS DAF

Manual Garcia, LLNL

Summary

Godiva is an unshielded, pulsed nuclear reactor, used to produce bursts of neutrons and gamma rays for irradiating test samples. The Godiva reactor is part of the TA-18 Facility at Los Alamos National Laboratory. The Godiva reactor is to be moved to the Device Assembly Facility (DAF) at the Nevada Test Site, northwest of Las Vegas, Nevada. Bursts of ionizing radiation from Godiva have been found to produce radio waves and electrical interference in circuits and electrical equipment (e.g., alarm systems, interlocks, recording devices) near Godiva.

Safety and security concerns regarding Godiva at the DAF are:

1. Can Godiva pulses induce detonators elsewhere in the DAF to explode?,
2. What is the expected strength of the electrical signal from Godiva elsewhere in the DAF?
3. Will Godiva pulses trigger security alarms, requiring additional administrative controls?

This report addresses these issues, and describes a brief set of electrical measurements intended to verify that electromagnetic emissions from Godiva are unchanged by its relocation, and below a threshold of safety for detonators that are outside the actual room Godiva resides in.

The following points will be described: the nature of Godiva electrical emissions, predicted electric field at a given distance, electromagnetic frequency, safety threshold for detonators, recommended “stay out” zone around Godiva for detonators, and recommended measurements to be made once Godiva has been installed at DAF.

Pulsed Compton Space Charge

The Godiva source is a radioactive metallic mass, about 30 cm in radius, atop a metallic tower, about 2 meters high. The pulse of radiation is produced when a piston of radioactive metal is quickly inserted and extracted from a cavity within the larger radioactive mass. The proximate masses form a critical assembly with chain reactions of atomic fission.

The release of gammas and neutrons percolate through the metallic mass, liberating photons and electrons –- known as Compton emission –- and gammas, neutrons, electrons and lower energy photons are emitted into space from the surface of the source. The gammas and neutrons emitted have a broad band of energies clustered at 1.5 MeV. The electron emission has a broad band of energy clustered at 300 keV.

Radiation drives electrons out of the source, making it positive. A return current flows down the stand, and the floor and room supply the rest of the circuit. The actual electron emitter is a layer about 10^-4 cm thick at the outer edge of the source, the thickness of this layer set by the range depth in uranium of electrons of about 300 keV. Electrons of hundreds of keV travel only about 1 to 2 cm in air, so the densest concentration of space charge will be in the first few centimeters of air about the source.

Gammas and neutrons flying through air ionize molecules, creating bipolar (neutral) space charge. This effect diminishes by the radial divergence of the flux. The recombination of bipolar space charge in air will occur over many microseconds, even possibly milliseconds because of the electrostatic charging of dust particles and water droplets, and because of the slow decay of collisionally excited metastable states of certain molecules and ions.

The quantity of unbalanced negative space charge about the source will determine the magnitude of the electric field extending from it. The length of the radiation pulse and the inductance and capacitance of the return circuit will determine the frequency of electromagnetic emission.

Magnitude of Effects

The radiation pulse is assumed to have these characteristics (Refs. 1 and 2):

R0 = 0.3048 m (1 foot), surface of emitter,

50 kRad of neutrons, interpreted as:
6000 J @ 2.5*10^16 neutrons of 1.5 MeV,

10 kRad of gammas, interpreted as:
1200 J @ 5*10^15 gammas of 1.5 MeV,

dt = 50 microsecond pulse of radiation.

Measurements of electromagnetic effects near Godiva in TA-18 are described in Ref. 3. The primary finding was a pulsed electric field, which caused a 4 V drop along a short length (not stated) of antenna at 2 meters from the source. The presence of an electric field was corroborated by a variety of other detectors ("D-dot, B-dot, tri-axial loop, 12 inch tri-axial dipole, 1 meter loop, 1 GHz monocone, current probe, short whip (RF), active whip, active E-field dipole"). The model to be described shows an electric field of several volts per centimeter at 2 meters from the source, a quantity similar to that observed.

Modeling the physics described above yields these results:

Q1 = 2*10^-7 C, electronic space charge within 1.5 cm of the source,
Q2 = 8*10^-7 C, for each of positive and negative ionization produced by gammas and neutrons within the same 1.5 cm layer of air.

The electric field at the outer radius of the space charge layer is 18.4 kV/m (184 V/cm), and the voltage drop across 1.5 cm is V1 = 276 V.

The electric field at a distance R from the center of the source (>R0) is given by (rounding the lead constant)

E(R) = (18 kV/m)*(R0/R)^2.

The following table shows sample values of the electric field at distance.

R/R0	E in V/m	R in meters for R0 = 1 ft	
1	18,000	0.305	
2	4500	0.61	
3	2000	0.914	
4	1125	1.22	
5	720	1.52	
6	500	1.83	
6.562	418	2.0	1st measurement station
7	367	2.13	
8	281	2.44	
9	222	2.74	
10	180	3.05	
15	80	4.57	1/4 wavelength @ 16.4 MHz
20	45	6.1	
25	29	7.6	
30	20	9.1	
100	1.8	30.5	
656.2	0.042	200	2nd measurement station

The notes in the table point to the two distances at which measurements were taken at TA-18 (Ref. 3), and to the distance equivalent of the quarter wavelength of electromagnetic radiation resonant with the LC return circuit.

The energy in the capacitive layer is U1 = (1/2)*Q1*V1 = 2.8*10^-5 J. Power would be about U1/dt = 0.6 W, and the peak power could be up to three times higher if details of pulse shape are considered. So, a reasonable estimate for power is ~1 W.

The capacitance of the charge layer is C = Q1/V1 = 7.3*10^-10 farad. The inductance of the return circuit will be L = (1.26*10^-7 henry/m)*(geometric factor with units of length in meters). Here, the geometric length scale of the return circuit is about 1 m, so the estimate of inductance is L = 1.3*10^-7 henry. The anticipated frequency of circuit ringing is

Ω = 1/sqrt(L*C) = 1.03*10^8 radians/s,
f = 16.4 MHz (wavelength = 18.3 m, period = 61 μs).

The estimate for RF emission is 1 W at 16 MHz.

Detonator Safety

A detonator can be considered a 1 meter antenna with an impedance of about 1 ohm that explodes when subjected to more than 100 V in a pulse with I^2*dt > 0.01 A^2*s, for current I (amps) and pulse width dt (seconds) (Ref. 4). This implies a current of over 14 A for a pulse of 50 μs. A higher impedance diminishes the hazard (less current is generated from the same electric field). The action integral multiplied by impedance is the energy supplied for initiation, and the threshold given here is 0.01 J.

In viewing the table, it is clear detonators further than 4.6 m (15 feet) are safe. Since the room in the DAF designed to house Godiva has a diameter larger than 30 feet, the simplest precaution is to prohibit detonators in the same room as Godiva.

Also, note that the estimated total energy of electromagnetic emission is 50 μJ, well below the action integral threshold of 0.01 J.

The initiation threshold for a detonator is specific to its type. The generic threshold used here is below that of the actual detonator types expected to be found at the DAF. Real detonators are expected to be more resistant to initiation by electromagnetic pickup than indicated by the generic threshold.

The model of pulsed compton space charge can be uncertain by a factor of three either way. Note that the predicted field at 2 m is 4 V/cm, and the LANL TA-18 measurement at that distance was 4 V across a probe (“short whip antenna”) of probably several centimeters length. Uncertainty by a factor of three does not change the key findings of the model: detonators should stay out of Godiva’s room or beyond 15 feet (5 m), and the energy of the electromagnetic field is 1/5000 (plus or minus a factor of three) of the generic detonator initiation threshold.

Tests

Modeling gives insight, but only measurement indicates reality. A test is recommended to both confirm and correct expectations based on theory, and to validate that moving Godiva does not result in an increase of electromagnetic emission.

Measurements should be taken at a minimum of two distances with a clear view of Godiva, where “clear view” is intended to mean a transparency to electromagnetic radiation (no intervening metallic shields). Earlier detectors had been placed at 2 m and 200 m, so 2 m should be used again, with another station farther out. The distances selected should include locations both within the boundaries of Godiva’s DAF space (room or cell or building), as well as outside it. A measurement made outside the Godiva room in the corridors of the DAF would give reassurance to any concerns about personnel safety.

The rest of this section is written as a recipe for a test. This is done to give an explicit description of a recommended procedure, which discriminates between true signal and background effects. Naturally, the actual details of a test plan will be set by those doing the measurements.

The same measurements should be taken at all distances.

A measurement station has eight separate channels. Four of these channels correspond to active detectors, and four others are paired detector-less wires, which are background channels. Each of the four active probes is paired by a parallel wire, in all respects identical except for the lack of detector. Background channels duplicate the path, shielding and wire type of their active counterparts.

The four detectors are of two types: electric field probe and B-dot probe. Each measurement station has two of each type of probe.

The two probes of a given type are oriented perpendicular to each other. One of the electric field probes is oriented along a radial line from the source, the other electric field probe would align with a circle about the source (perhaps horizontal). One of the B-dot probes would be aligned with its loop in a vertical meridian (plane at constant azimuth relative to Godiva's axis), the other B-dot probe would have its loop area in a horizontal plane.

The data should give electric field and B-dot at two orientations. Each active detector will be paired with a background channel, and the difference of these signals should be effects at the detector alone. The background signals will show the magnitude of the combination of antenna effects (which should be absent with coaxial cable with the shield grounded) and radiation induced ionization within the cable (Compton emission from the core, and charging of the insulator).

Conclusions

From modeling, it seems that Godiva cannot initiate detonators, unless they are in close proximity within the same DAF room (and unlikely even then).

Electric field and B-dot measurements at two or three distances from Godiva would help to determine the spatial distribution of electrical effects, and their frequency.

Probes paired with background channels would help to isolate the signature of electromagnetic emission from ionizing radiation-induced cable noise. Also, data where each measurement was taken at two perpendicular orientations would help to determine the nature of the return circuit –- the electromagnetic emitter.

Data taken at TA-18 prior to the move (see Refs. 1 and 3) and at DAF after the move will help to verify that electromagnetic emission will be as expected. If not, then the data would be the basis upon which to revise the extent of the "stay-out" zone for detonators, and an impetus to reexamine the operation of Godiva itself.

References

1. The source experiences 1.8*10^14 fissions/°C for source temperature rise dT, such that 40 °C < dT < 225 °C. Data from LA-CP-01-472, "Results Of A Radiation Shielding and Electromagnetic Interference Study to Support the TA-18 Mission Relocation Project," S. D. Clement, R. E. Malenfant, B. G. Rees, 30 October 2001. The density of the uranium mass prevents most fission fragments and radiation from escaping. Assuming one escaping gamma photon or neutron of 1.5 MeV per fission reaction implies an emission of between 1.7 kJ and 9.7 kJ. A total emission of 7.2 kJ was used in the text as a basis for estimating electromagnetic effects

2. Michael Bland (LLNL-DSED) reports Godiva emission as follows (based on communications with TA-18 personnel): 50 kilo-Rads of 1-2 MeV neutrons at 1 foot, 10 kilo-Rads of 1-2 MeV gammas at 1 foot, pulse width of 50 microseconds. This corresponds to a total of 7.2 kJ, see text.

3. Steven Clement, "Detection of Fissioning Systems and SNM through EM Radiation," 2005 viewgraph presentation (LANL, unclassified, no report number), cites (1).

4. Michael Ong (LLNL-DSED) reports this general set of parameters as a threshold condition for spurious initiation of detonators: antenna length of 1 m, with an overall voltage drop of 100 V and an action integral of 0.01 A^2*s. The action integral is the time integration of current squared, assuming a 1-ohm impedance.